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Effect of Randomized PI Controller in Off Grid Network

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Abstract: Off-grid connection of photovoltaic (PV) system use power electronic components such as inverters and supply a non-linear load as users. This produce harmonics which adversely affect the power quality of the distribution network. A sinusoidal pulse width modulation (SPWM) of the voltage source inverter (VSI) is proposed to act as a switching pulse. The scheme to mitigate the harmonic problem and phase error in single-phase full bridge inverter is considered using low pass filter and current controller. The current control parameter using a conventional Proportional Integral (PI) is simulated. This is extended with the modification of control method where randomization control parameter technique is added to produce a more efficient current controller system by using a random integral gain to the system. Result shows the latter technique is better for reduction of harmonics rather than conventional PI controller technique.

Keywords: Harmonics, current controller, off grid network system.

1. Introduction

Nowadays, the term off – grid network refers to not being connected to a grid or far from existing national electrical grid [1][2].

In electricity, off-grid can be stand-alone power system or mini-grids typically to provide a smaller community with electricity. Off-grid electrification is an approach to access electricity used in countries and areas with little access to electricity, due to scattered or distant population. It can be any kind of electricity generation. One solution to resolve the fluctuation of output power from those renewable energies is energy storage devices [3]. Basically, these devices manage to give comprehensive in community off – grid network or mini grid where it consists of PV panel, battery, induction motor, synchronous generator, inverter and else.

In March 2016, issue from IEEE Electrification Magazine, the article "Fueling Sustainability" is discussed where IEEE's hand already ensuring the alternative means for basic electricity services to the world's off-grid communities. The transformation for empowered electricity is been illuminating in distributed wind and solar system. With this introduction of electricity, it will have regarded as a keystone to overcoming poverty, dramatically enhancing quality of power system, and encouraging sustainable community prosperity [4].

The majority of off-grid systems connected directly to an AC network resulting in clusters of isolated, power-limited, single failure-prone networks. As an example, power electronic circuitry like inverter, filter and rectifier technology has an important role to have safe and reliable grid interconnection operation of renewable energy systems. It is also necessary to generate a high-quality power to the off-grid with reasonable cost. For this reason, up to date technologies of power electronics devices are applied for this circuitry. They must be able to provide high efficiency conversion low harmonic distortion. In this paper, a modification of conventional Proportional Integral (PI) controller is proposed to minimize the low order harmonics in the off-grid connected systems.

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According to the IEEE standards [6] and IEC [7], the Total Demand Distortion (TDD) of the current injected to the grid and the Total Harmonic Distortion (THD) of voltage should be lower than 5%. Then, different parameters from controller methods are proposed to obtain lower harmonic distortion. This controlling method propose a new control model based on the adaptive PI controller, which can randomized and self-adjust the parameter of control gains during disturbance such that the performance always matches a desired response, regardless of the change of operating condition. Since the adjustment is autonomous, this gives the results show that the controller achieves plug-and-play capability for remote off-grid networks.

2. Literature

The important overview has been carried out which related with harmonic injection and power quality improvement in off-grid system.

A. Harmonic Injection

Lorenzo Cividino et al [8] describes that harmonic distortion acts as production of unwanted frequency component with multiple integer of fundamental frequency. The investigation of harmonic injection that effects in non-linear load is been carried out in this paper. The result that drawn from the harmonic behaviour shows the typical triplen odd harmonics with multiple of fundamental frequency of 3rd, 9th, and 15th.

The current controller mostly has significant effect on the quality of the current supplied to the grid or off-grid system and it is important that the controller provides a high quality sinusoidal output with minimal distortion to avoid creating harmonics. The application of PI current controller connected with inverter has been proposed by Daniel Zammit et al [9]. He demonstrates single phase 3kW grid connected PV inverter by including the LCL filter and current control to mitigate the harmonic generated by these inverter and limit adverse effects on the grid power quality.

B. Power Quality Improvement in Off-Grid System

The method of randomized technique has been proposed earlier to reduce THD in inverter system connected to the grid [10]. However, the development of power quality problem in off-grid network by improving the power electronic converter such as inverter topology, PWM switching schemes, filter arrangements, and others can be possible to make. Alternatively, it is also possible to enhance the performance and robustness of the current controller. In a paper from Sergey A. Temerbaev et al [11] describes that high penetration of non-linear loads give serious impact in power quality, especially for off-grid power systems. Harmonic distortion produced by non-linear loads causes several problems such as increased power losses in customer equipment, power transformers, and flicker. Therefore, the improvement to mitigate the harmonic is proposed with the help of passive power filters (PPF) and active power filters (APF) that connected to non-linear load which includes a rectifier with RL load on the dc side. The results show that the THD non-linear load current is 21.4%. With PPF connected, THD current is decreased to 18.8% while the second part is APF connection that resulting THD current equal to 3.12%.

A study of Ali Algaddafi et al [12] mentioned that the power quality improvement in off-grid system is better rather than the grid utility network. The configuration of stand – alone inverter is used to test the power quality in off –grid system compares with the power quality toward grid system. The analysis is made on by referring THD output voltage and current of stand- alone inverter after filtering with LC filter. The performance of proposed controller for stand-alone inverter also has been evaluated in this paper. By simulation, it is shown that THD obtained for the output current for off grid system is 1.123% and 1.6% when it supplied with grid network. While THD for output voltage in off-grid system is 1.6% compared with connected in grid systems which are 2.5%.

The most recent research was presented by Ritu Sharma et al [13]. She claimed that off-grid distribution system facing poor power quality of harmonic injection due to non-linear load used in domestic application. Therefore, the performance of PI controller with the proportional and integral gain setting has been proposed in this research to enhance the power quality problem. In her work, non-linear load is simulating with diode bridge rectifier feeding resistive load follow by appropriate PI controller with trial and error tuning method. Then, the FFT analysis showed an improvement THD in load current where it decreases to 4.28% rather than 29.35%. Another paper has also done the analysis in single phase inverter system connected to non-linear load using PI controller [14]. The study able to reduce current THD bu using the simple trial and error tuning method.

In this paper, it presents the results of THD output current when randomized technique is applied to the conventional PI current controller with non-linear load off-grid system. The tuning method used in the trial and error method.

3. Methodology

The modelling of power system circuit is conducted using Simulink which supports in linear or nonlinear system. The construction of power system circuit such as inverter, filter, transformer, and rectifier starts without adding a conventional PI controller to observe the first harmonic analysis using the Fast Fourier Transform (FFT). FFT analysis uses PowerGui which has capability to display steady-state values of measured current and voltage for modelling circuit from the Scope detail. Therefore, by sampling time in PowerGui block, THD analysis can be identify whether the whole modelling system is maintained more than 5% or not. After that, PI controller circuit design is being added together with power system circuit by connected from feedback inverter output current as follows with non-linear load. The reference signal for PI control is taken from inverter current and voltage while their output will go to PWM reference signal. The main thing in this circuit is the proportional gain and integral gains are being included by using trial and error method.

The comparison started with the result of harmonic behaviour in inverter system without PI current controller and with PI current controller. Follow by that, the comparison between conventional and randomization gain in PI current controller also been analyse in detail. The collected data would show the differences between both of them in term of harmonic mitigation solution. Figure 1 shows the system block diagram designed in Matlab Simulink.

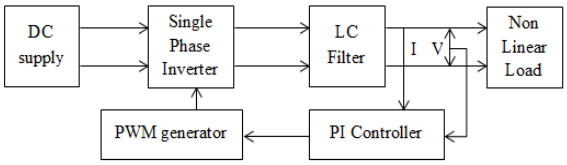

Fig. 1 Block diagram of PI controller with stand alone system

4. Results and Discussion

A. Without PI Controller

Without adding PI controller, which means without any feedback circuit in the system, the result of FFT analysis for the load current is shown in Figure 2 to observe the pattern waveform that been created and harmonic cause by non-linear load. The result shows a THD of 26.03% for the load current with 0.4772A. This data from FFT analysis is transferred to Excel as shown in Figure 3.

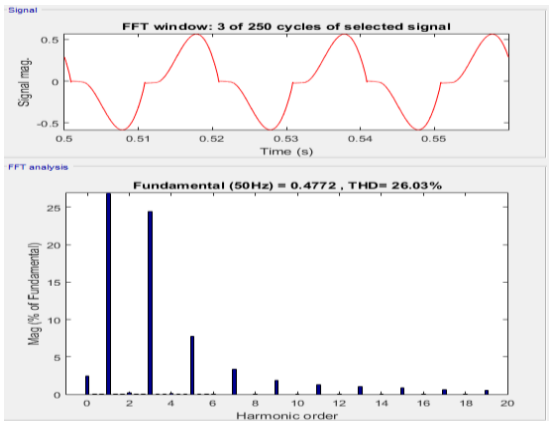

Fig. 2 FFT analysis of Load Current without controller

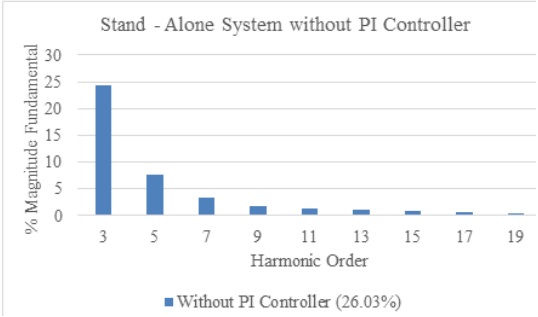

Fig. 3 Odd Harmonic Order for Stand-Alone System without PI Controller

In this case, the magnitude of current distortion is decrease from lower harmonic order until high harmonic order due to impedance from non-linear load. This characteristic is referred to Ohm's Law where impedance is inversely proportional to the current, I = V/Z. Therefore, 3rd harmonic order has high magnitude current distortion because of less impedance drawn by non-linear load.

B. With Conventional PI Controller

The stand-alone system is then simulated together with conventional PI controller and the value of Kp and Ki are tune by using trial and error method. Using this method, any gain more or less than this value will produce worse waveforms. The obtained gaining value chosen are Kp=0.6 and Ki=0.000000006. Result of FFT analysis is done and shown in Figure 4 with a total harmonic distortion of 3.80% and current peak 0.0015A for load current waveform.

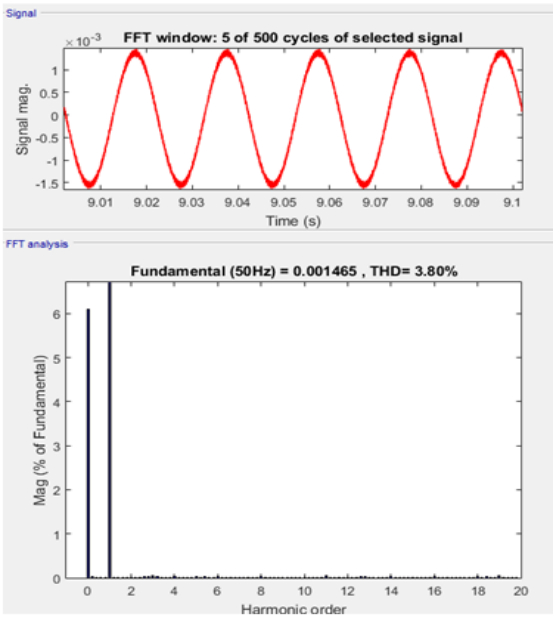

Fig. 4 FFT analysis of Load Current with PI controller

Once again this FFT analysis data is collected and transferred using Excel. The result can be shown in Figure 5. The load current with conventional PI current controller shows a THD of 3.80% with current distortion in triplen harmonics order which is 3rd, 9th, and 15th. This sequence occur because of current distortion is circulating in the additive neutral from the step down transformer.

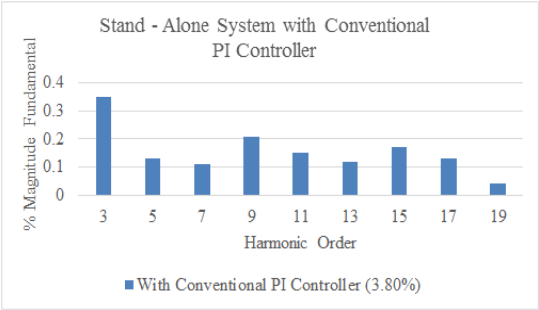

Fig. 5 Odd Harmonic Order for Stand-Alone System With Conventional PI Controller

C. With Randomized PI Controller

This time, the system is adjusted so that the integral gain of the controller is automatically tuned within specific range. The stand-alone system now is simulated with randomized PI discrete controller and the chosen gaining value still same where Kp and Ki equal to 0.6 and 0.000000006 respectively, but additional random number is established with Ki gain. The random signal generation that been added for randomization characteristic is shown in Figure 6 below. The limit value for this random number is approximately between 1 x 10^{-6} and -1 x 10^{-6}.

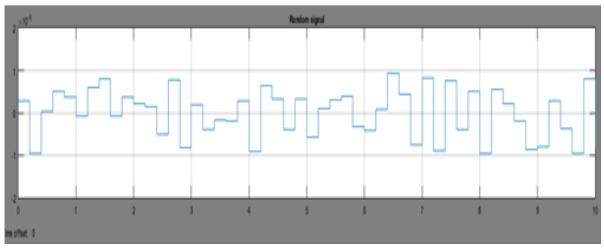

Fig. 6 Random Signal Generation

The FFT analysis once again has been done and the result are shown in Figure 7 with a total harmonic distortion of 3.58% and current peak 0.0016 A for load current waveform.

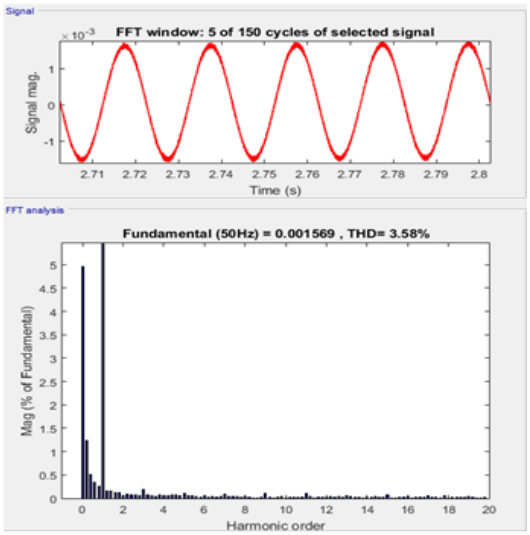

Fig. 7 FFT analysis of Load Current with randomized PI controller

The harmonic order has been transferred again into Excel and it can be shown in Figure 8. As we can see, the triplen harmonic of 3rd, 9th, and 15th once again dominates as a high magnitude of current distortion rather than other harmonic order. The additional signal from random number in PI controller causes the improvement of reduction magnitude current distortion when compared with previous result using conventional PI controller.

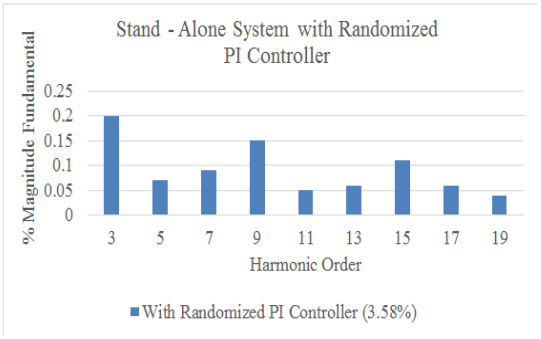

Fig. 8 Odd Harmonic Order for Stand-Alone System with Randomized PI Controller

D. Comparison between Conventional and Randomized PI Controller in Stand-Alone System

The harmonics level in load current without using controller action has high harmonics compared with the implemented of PI control technique. This control technique can be compared as conventional PI current control techniques greatly reduce the THD of 26.03% to 3.80%. While randomized PI current control techniques shows us better harmonic reduction even there are slightest harmonic drops from 3.80% to 3.58% of the fundamental frequency. The comparison between conventional and randomized PI controller technique for harmonic mitigation in stand-alone system can be shown as in Figure 9.

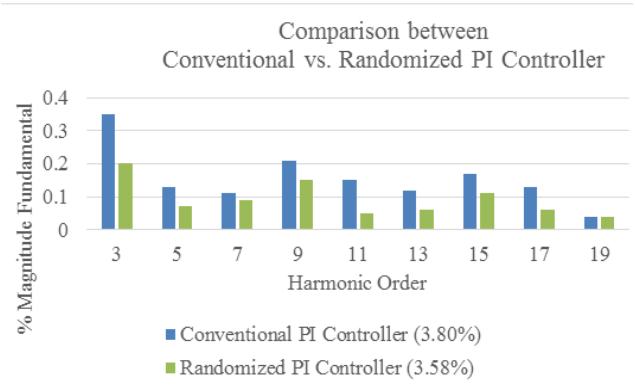

Fig. 9 Harmonic Comparison between Conventional PI and Randomized PI Controller

The bar results in the Excel has shown the randomized PI controller technique is better for reduction of harmonic rather than conventional PI controller technique. As we can see, randomized PI controller technique has a tendency to reduce harmonic distortion by considering odd harmonic order with 3rd, 5th, 7th, 9th, and 11th where the result was 0.20%, 0.11%, 0.09%, 0.11% and 0.11%. While by conventional PI technique, the result based on their odd harmonic order was 0.35%, 0.13%, 0.11%, 0.21%, and 0.15%. Comparing these techniques, the most dominant harmonic order which successfully reduced harmonic is 3rd harmonic where it reduces to 0.2% from 0.35%. Normally, it difficult to reduce but using the randomized technique the percentage of reduction on 3rd harmonic is calculated with 75%.

5. Summary

The development of conventional PI and randomized PI controller to eliminate the harmonic distortion in off-grid network has successfully been done. This method can be possibly applied and can be used in other applications as well. From the comparison, using the randomized PI controller, it can further reduce the magnitude of odd harmonics in the load current and thus not possible to improve power quality when it comes to higher rating off grid system.

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